Earthquake Probability Example

The probability, P, that an earthquake can occur within a certain time frame, t_L, can be estimated using Poisson's distribution:

$$P = 1 - e^{-\lambda_a t_L}$$

For example, assume the average return time or recurrence of an earthquake is 100 years, estimate the probability that it will occur in the next 100 years.

Let T_a = mean return period in years = $1/N_a$

where: $N_a = \lambda_a$ = average annual probability that the peak ground acceleration will exceed a certain acceleration, "a".

In a typical design situation, the designer is interested in the probability that such a peak exceeds "a" during the life of the structure, t_L.

For the earthquake recurrence example, $T_a = 1/N_a = 1/100 = 0.01$ and $t_L = 100$ years:

$$P = 1 - e^{-\lambda_a t_L} = 1 - e^{-0.01(100)} = 0.63 \text{ or } \underline{63\%}$$

Using the same earthquake, determine the chance that the same earthquake will occur within the next 20 years:

$$P = 1 - e^{-\lambda_a t_L} = 1 - e^{-0.01(20)} = 0.18 \text{ or } \underline{18\%}$$

An earthquake with a peak ground acceleration coefficient map (see Figures 4.3.1 and 4.3.2) with a 10% probability of exceedance in 50 years corresponds to a return period of 475 years.

Proof: $T_a = 475$ years, $N_a = \lambda_a = 1/475$ and $t_L = 50$ years

$$P = 1 - e^{-\lambda_a t_L} = 1 - e^{-(1/475)(50)} = 0.0999 \text{ or } \underline{10\%} \text{ Checks}$$

Earthquake Probability - Poisson Model

Figure 4-A-1

Earthquake Restrainer Example

Bridge Type: Multiple Simple Spans

This Design Example is based on CALTRAN's *Seismic Design References* (1997)

Seismic Data: Acceleration Coeficient, A = 0.3g; Soil Type II, S = 1.2
Dead Load of the Span = 540 kips

Bearings: Roller Bearings with no longitudinal restraint. Shear blocks to be added to provide transverse restraint.

Restrainers: 20 foot long High-Strength steel rods (ASTM F1554 Grade 105)
F_y = 105 ksi and E = 29,000 ksi
2 inch gap at end of High-Strength rod

Design Examples of Seismic Retrofits
Figure 4-A-2

Calculate Available Seat Width: (22”/2) – 4” –1” = 6 inches

Determine Maximum Restrainer Deflection (D_r):

Let D_y = max. elastic deformation of rod when restrainer is stressed to F_y

$D_y = F_y L/E$ = (105 ksi)(20ft)(12in/ft)/(29,000 ksi) =	0.9 inches
D_{gap}	2.0
D_r = Resultant Longitudinal Displacement = $D_y + D_{gap}$ =	2.9 inches < 6 inches

Try four 1 inch diameter rods: $A_g = 4(0.785 in^2) = 3.14\ in^2$ Use A_g of plain rod for stiffness/ elongation calculations and use tensile area, A_t, for stress check.

(Note: $A_g = A_t$ if a high strength rod is threaded for its full length):

Calculate the stiffness, K_t ,provided by the restrainer rods:

$$K_t = \frac{F_y(A_g)}{D_r} = \frac{105(3.14)}{2.9} = 114 kips/inch$$

Calculate the period, T:

$$T = 2p\sqrt{\frac{W}{gK_t}} = 0.32\sqrt{\frac{540}{114}} = 0.70 \sec onds$$

where: T = period in seconds
W = Dead Load of the span = 540 kips
$g = 32.2\ ft/sec^2 \times 12 in/ft = 386\ inches/sec^2$
K_t = 114 kips/inch

Design Examples of Seismic Retrofits ***(Continued)***

Figure 4-A-2

Calculate the Elastic Seismic Response Coefficient, C_S, for Multimodal Analysis:

$$Cs = \frac{1.2AS}{T^{2/3}} = \frac{1.2(0.30)(1.2)}{0.70^{0.67}} = 0.55g$$

when A $\geq$ 0.30g, Cs need not exceed 2.0A

Therefore, C_S = 0.55g < 0.6g, okay

Calculate the seismic force and tensile stress, f_t, to be resisted by the restrainers:

Use tensile area: A_t = 0.606 in^2 per restrainer rod

Seismic Force = C_SW = 0.55(540) = 297 kips

$$f_t = \frac{C_s W}{A_t} = \frac{297}{4(0.606)} = 122.5ksi > 105ksi$$

No Good for Stress

Calculate the elastic elongation in the four 1 inch diameter retrainer rods, D_t:

$$D_t = \frac{C_s W}{K_t} = \frac{297}{114} = 2.6inches < D_r = 2.9inches$$

okay

The elastic elongation of the restrainers is less than the resultant displacement. However, the tensile stress at the threaded ends of the rod exceeds fy. Therefore, it is necessary to increase the number of restrainers or increase the diameter of the restrainers in order to reduce the elastic elongation.

Try four 1-1/8 inch diameter x 8UN threaded rods: A_g = 4(0.994 in^2) = 3.98 in^2

$$K_t = \frac{F_y(A_g)}{D_r} = \frac{105(3.98)}{2.9} = 144kips/inch$$

$$T = 2p\sqrt{\frac{W}{gK_t}} = 0.32\sqrt{\frac{540}{144}} = 0.62\,\text{seconds}$$

$$Cs = \frac{1.2AS}{T^{2/3}} = \frac{1.2(0.30)(1.2)}{0.62^{0.67}} = 0.60g = 0.6g$$

$$D_t = \frac{C_s W}{K_t} = \frac{0.6(540)}{144} = 2.25inches < D_r = 2.9inches$$

okay for Elongation

$$f_t = \frac{C_s W}{A_t} = \frac{324}{4(0.790)} = 102.5ksi < 105ksi$$

okay for Stress

Use four 1-1/8 inch diameter x 20 ft long ASTM F1554 Grade 105 High-Strength Rods with Fy = 105 ksi. Specify a Charpy V-Notch (CVN) of 25 ft-lbs @ 40°F, or Supplemental Requirement S5 (15 ft-lbs @ -40°F.***BRIDGE DESIGN MANUAL***

Design Examples of Seismic Retrofits ***(Continued)***
Figure 4-A-2

Circular Column Steel Jacket Retrofit Example

Lateral tie reinforcement of #4 bars at 12” centers is inadequate confinement for the longitudinal column reinforcement.

Concrete core is adequate to resist seismic transverse shear force

The column is 3 ft. in diameter. Assume clearance is 1” between column and steel jacket.

Determine thickness of steel jacket.

Using the FHWA Guidelines from *Seismic Retrofitting Manual for Highway Bridges*, (1995):

$$t > \frac{f_{cc}D}{58}$$

where: t = thickness of steel jacket in inches
f_{CC} = confining concrete core pressure in ksi = 0.300 ksi
D = 36” + 2” = 38”

$$\therefore t = \frac{(0.3)(38)}{58} = 0.20'' > 0.25'' \text{ min}$$

Use 1/4” thick steel jacket with Fy = 36 ksi

Lateral tie reinforcement of #4 bars at 12” centers is inadequate confinement for the longitudinal column reinforcement.

Concrete core is adequate to resist seismic transverse shear force

The column is 5 ft. in diameter. Assume clearance is 1” between column and steel jacket.

Determine thickness of steel jacket.

Using the FHWA Guidelines from *Seismic Retrofitting Manual for Highway Bridges*, (1995):

$$t > \frac{f_{cc}D}{58}$$

where: t = thickness of steel jacket in inches
f_{CC} = confining concrete core pressure in ksi = 0.300 ksi
D = 60” + 2” = 62”

$$\therefore t = \frac{(0.3)(62)}{58} = 0.32'' > 0.25'' \text{ min}$$

Use 3/8” thick steel jacket with Fy = 36 ksi

A seismic analysis shows the 4 ft. diameter column is required to undergo a plastic drift angle of 0.045 radians.

The existing lateral confining reinforcement is inadequate.

Longitudinal bars are #11 Grade 40 reinforcement and ρ_l = 0.04 or 4 %.

Design Examples of Seismic Retrofits ***(Continued)***
Figure 4-A-2

The ratio $\dfrac{P}{f'_{ca} A_g} = 0.2$

where: P = resultant axial force in kips

f'ca = 1.5(f'c) ≈ 5 ksi for an original concrete design strength of 3,000psi

Ag = gross concrete column area in in^2

Determine $\dfrac{t_j}{D} \geq 0.01$ from Figure 8.5(a) *Seismic Design of Bridges*, Priestley, Seibel, and Calvi (1996), p. 592

$$\therefore t_j = 0.01(48+2) = 0.50''$$

Use ½" thick steel jacket with Fy = 36 ksi

Lateral tie reinforcement of #4 bars at 12" centers is inadequate confinement for the longitudinal column reinforcement.

Concrete core is adequate to resist seismic transverse shear force

The size of the rectangular column is 2' x 6'

Check size of ellipse to provide 1" clearance between column and steel jacket.

$$\frac{x^2}{a^2} + \frac{y^2}{b^2} = 1$$

After several tries, use an elliptical shape such that:

Long axis = 7'-2" such that $a = 3'-7''$ and

Short axis = 4'-2" $b = 2'-1''$

Design Examples of Seismic Retrofits ***(Continued)***

Figure 4-A-2

Find equivalent diameter, D = 2a = 86"

Using the FHWA Guidelines from *Seismic Retrofitting Manual for Highway Bridges*, (1995):

$$t > \frac{f_{cc} D}{58}$$

$$\therefore t = \frac{(0.3)(86")}{58} = 0.44"$$

Use ½" thick steel jacket with Fy = 36 ksi

Lateral tie reinforcement of #4 bars at 12" centers is inadequate confinement for the longitudinal column reinforcement.

Concrete core is adequate to resist seismic transverse shear force

The size of the rectangular column is 4' x 6'

Check size of ellipse to provide 1" clearance between column and steel jacket.

$$\frac{x^2}{a^2} + \frac{y^2}{b^2} = 1$$

After several tries, use an elliptical shape such that:

Long axis = 8'-2" such that $a = 4'-1"$ and

Short axis = 6'-2" such that $b = 3'-1"$

Find equivalent diameter, D = 2a = 98"

Design Examples of Seismic Retrofits ***(Continued)***
Figure 4-A-2

Using the FHWA Guidelines from *Seismic Retrofitting Manual for Highway Bridges*, (1995):

$$\therefore t = \frac{(0.3)(98")}{58} = 0.51"$$

Use ½” thick steel jacket with Fy = 36 ksi

Design Examples of Seismic Retrofits ***(Continued)***
Figure 4-A-2